Inchworm®-HMR (Hybrid MEMS Ratchet) High-Power Piezoelectric Actuator

Presented By:

David Henderson
Director of Positioning Products
Burleigh Instruments, Inc.

Overview of Burleigh Instruments, Inc.

- **Located 20 miles Southeast of Rochester NY**
- **~ 100 employees**
- **Two Divisions**

Optical Instruments Division
Laser Wavelength Measurement for Fiber Optic Communications Systems **(Wavemeter®)**

Positioning Products Division
Piezoelectric-based positioning systems for optics, photonics, life science and nano-technology applications. **(Inchworm ®)**

Program Participants

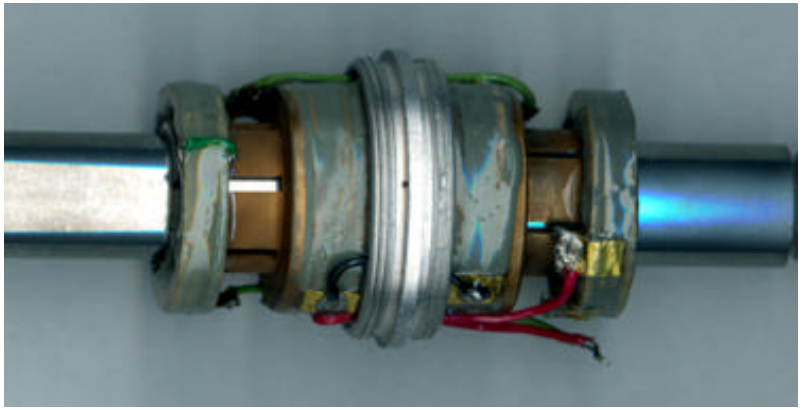
DARPA -CHAP
- Dr. Ephrahim Garcia

Kirtland AFB
Air Force Research Lab
DOT (Deployable Optical Telescope) Program
- Dr. Benjamin (Kyle) Henderson

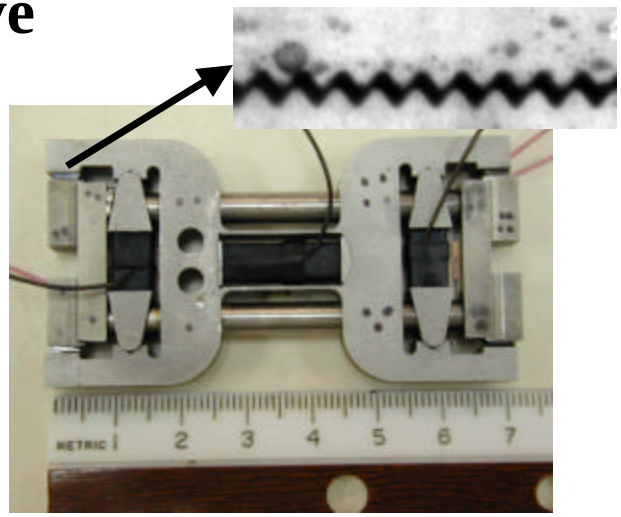
Burleigh Instruments, Inc.
Positioning Products Division
- David Henderson
- Dr. Qin Xu
- Alex Martens
- John Fasick
- Jim Smith

UCLA
Active Materials Laboratory
- Professor Greg Carman
- Dr. Quanfang Chen

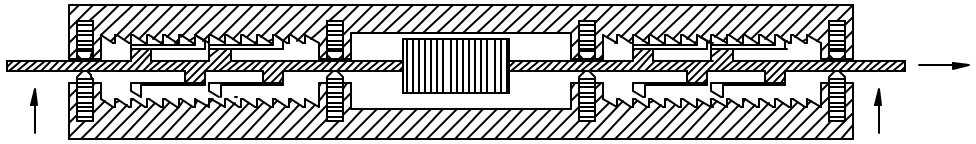
Program Objective



Burleigh's Classic Inchworm



UCLA's Mesoscale Actuator Device (MAD)



Inchworm-HMR with Drive Electronics

Performance Goals For Inchworm-HMR

Maximum Push Force (Simultaneous with Maximum Speed)	225 N
Maximum Speed (Simultaneous with Maximum Force)	50 mm/s
Travel	30 mm (a)
Size	10 X 10 X 70 mm (a)
Mass	40 g
Position Resolution	Less than one nanometer. (b)
Position Accuracy	Less than one micrometer.(c)
Ratchet Teeth Pitch	10 μm
Maximum Motor Frequency	5 KHz
Direction Reversal Time	Less then 10 ms
Power Density (Force X Speed /Mass)	281 W/Kg
Drive Electronics	Single PCB with 24 volt input.

Notes for Table 1:

a. The INCHWORM-HMR motor length is proportional with travel. Shorter travel will reduce the length and mass.

b. The position resolution is determined by the resolution of the extension actuator.

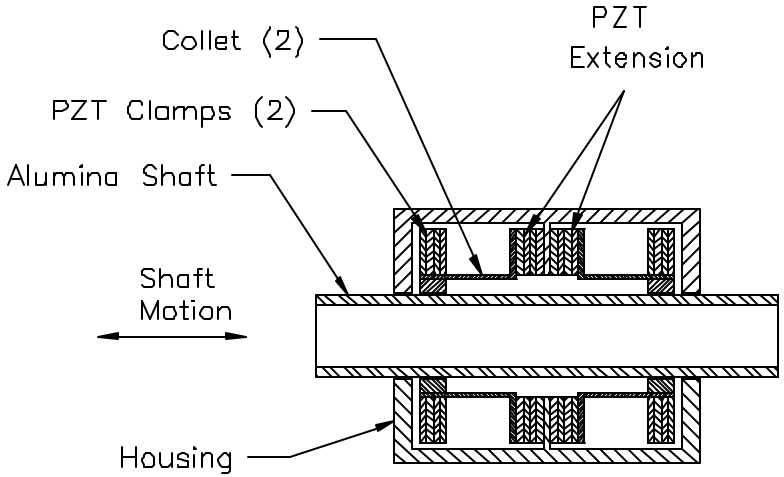
c. The position accuracy is determined by the pitch accuracy of the MEMS teeth and measurement method.

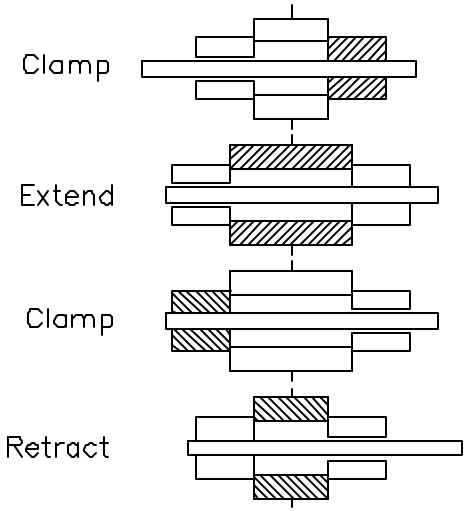
Program Schedule

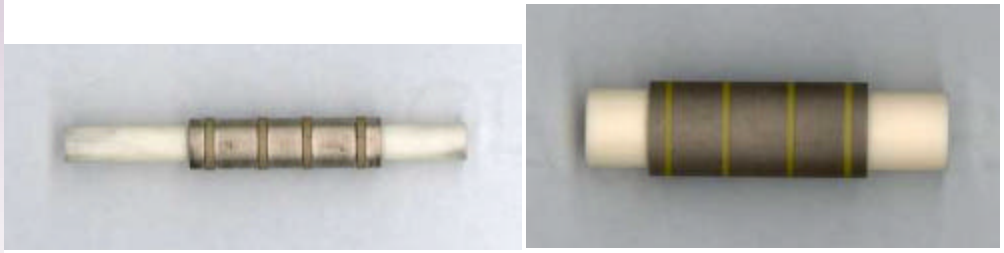
Start Date is June 22, 2000

Tasks	**2000**		**2001**				**2002**				**2003**	
Quarters	3	4	1	2	3	4	1	2	3	4	1	2
Phase 1- Proof of Concept												
1A. Ratchet Module Design/Model/Test												
1B. Design MEMS Teeth/Flexure (UCLA)												
1C. Fabricate MEMS Teeth/Flexure (UCLA)												
1D. Extension Actuator Design/Build/Test												
1E. Extension Actuator Evaluation (UCLA)												
1F. INCHWORM-HMR Build-Test												
1G Drive Electronics Design/Build/Test												
Phase 2 – Prototype												
2A. Ratchet Module Design/Test												
2B. MEMS Teeth/Flexure Build/Test (UCLA)												
2C. Extension Actuator Build/Test												
2D. Extension Actuator Fatigue Testing (UCLA)												
2E. INCHWORM-HMR Build/Test												
2F. Drive Electronics Design/Build/Test												
2G. DOD and Commercial Applications Testing												

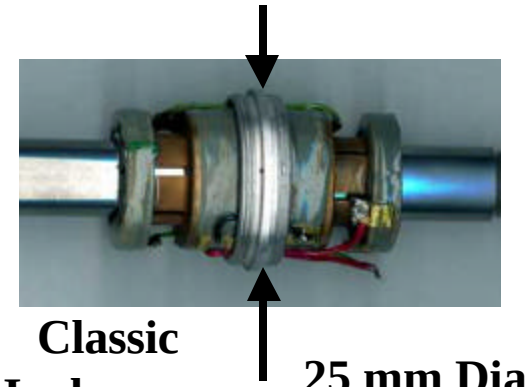
Classic Inchworm® Piezoelectric Stepping Motors (1975 to Present)







Single Tube Inchworm Motors for Ultra High Vacuum (Large and Small)



Classic Inchworm

25 mm Dia.

Classic Inchworm Performance

- Nanometer resolution.
- Greater than 100 millimeter range.
- Push forces greater than 15 Newton's.
- Speeds greater than 1 mm per second.
- Very high stiffness, >10 N/micrometer.
- Solid state construction.
- Direct linear motion.
- Ultra High Vacuum compatible.
- Very low heat dissipation.
- Manufactured for 25 years.

Classic Inchworm "Wish List"

Desired Feature	Benefit
Reduce "glitch" when changing state of clamps. *(Classic IW is <50 nm)*	Constant velocity movement and improved control with Nanometer precision.
High holding force when power is removed. *(Classic IW can be zero.)*	Fail-safe operation. Low-power operation.
Precise position is maintained when power is removed. Self-locking without changing position. PZT is out of load path. *(Classic IW moves at least a few micrometers.)*	Next Generation Space Telescope *(NGST) and other adaptive optics systems that need hundreds of actuators multiplexed to one set of drive electronics. Long term passive stability at Nanometer level.
Operation at over wide temperature range from ambient to 20 Kelvin. (*Classic IW looses mechanical fit and 80 percent of PZT strain.)*	NGST *

* Burleigh is currently completing a Phase 2 SBIR program with NASA Langley to develop an NGST Inchworm.

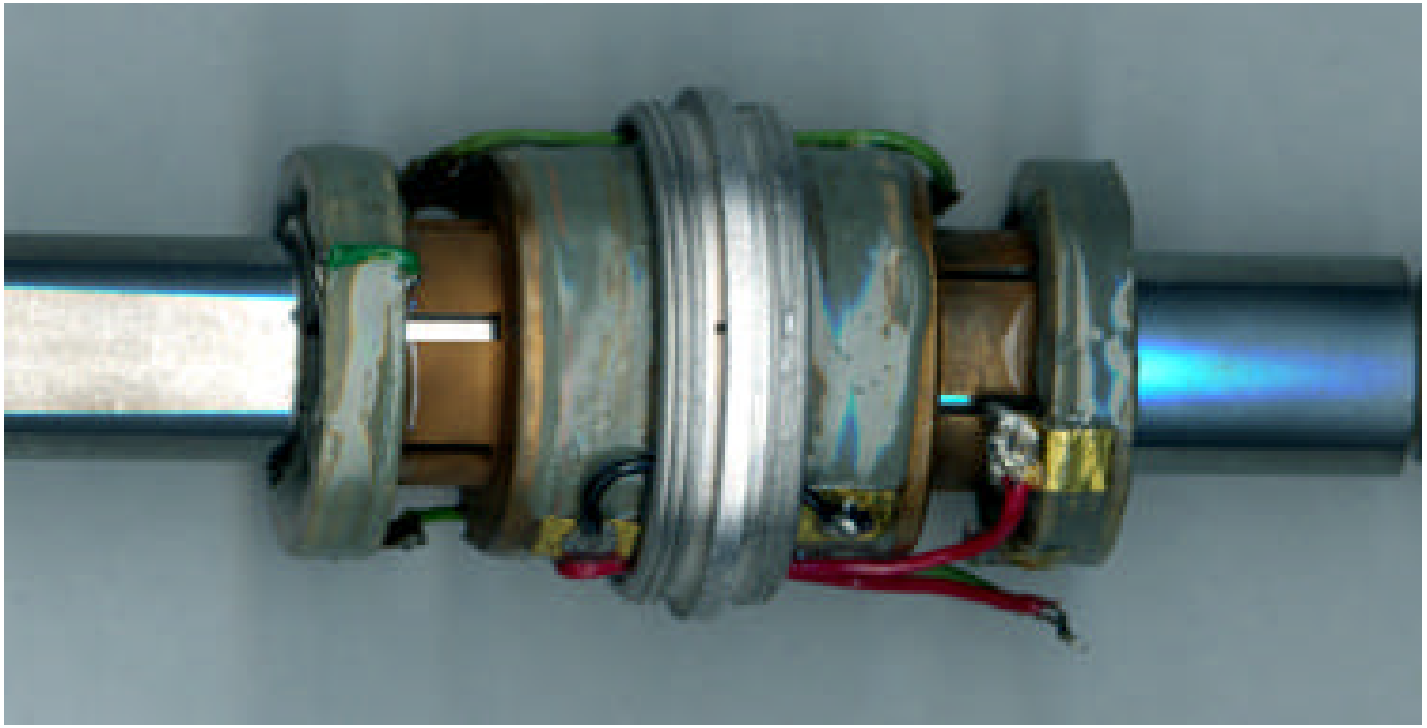
Classic Inchworm "Wish List"

Desired Feature	Benefits
Improve motor lifetime by at least a factor of 100 by minimizing wear and eliminating all stresses on PZT elements except compressive. *(Classic IW life is ~ 2000 meters.)*	Needed for industrial and aerospace applications.
Increase driving force by at least a factor of 10. *(Classic IW force is 15 Newtons)*	Needed for high powered applications such as shape control, adaptive optics, and vibration damping.
Increase speed by at least a factor of 10. *(Classic IW speed is 1 mm/second)*	Needed for high-speed alignment, shape control and industrial processes such as semiconductor manufacturing and photonics automation.
Reduce size and weight. . *(Classic IW mass is ~ 10 grams. Diameter is 25 millimeters.)*	Aerospace shape control and adaptive optics, six degree-of-freedom microrobotics and OEM applications.

These desired features match the goals of the Inchworm-HMR.

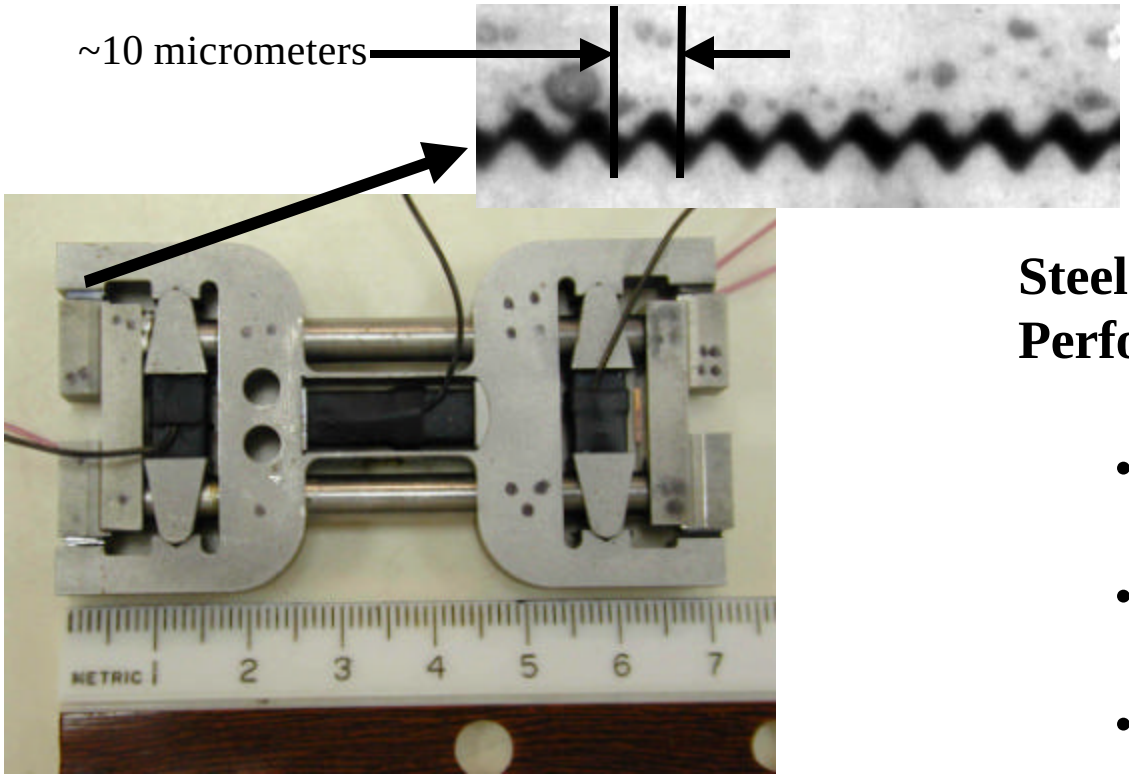
Increasing Push Force

Classic Inchworm push force is limited by the friction of the smooth clamps on the smooth shaft.



Increasing Push Force

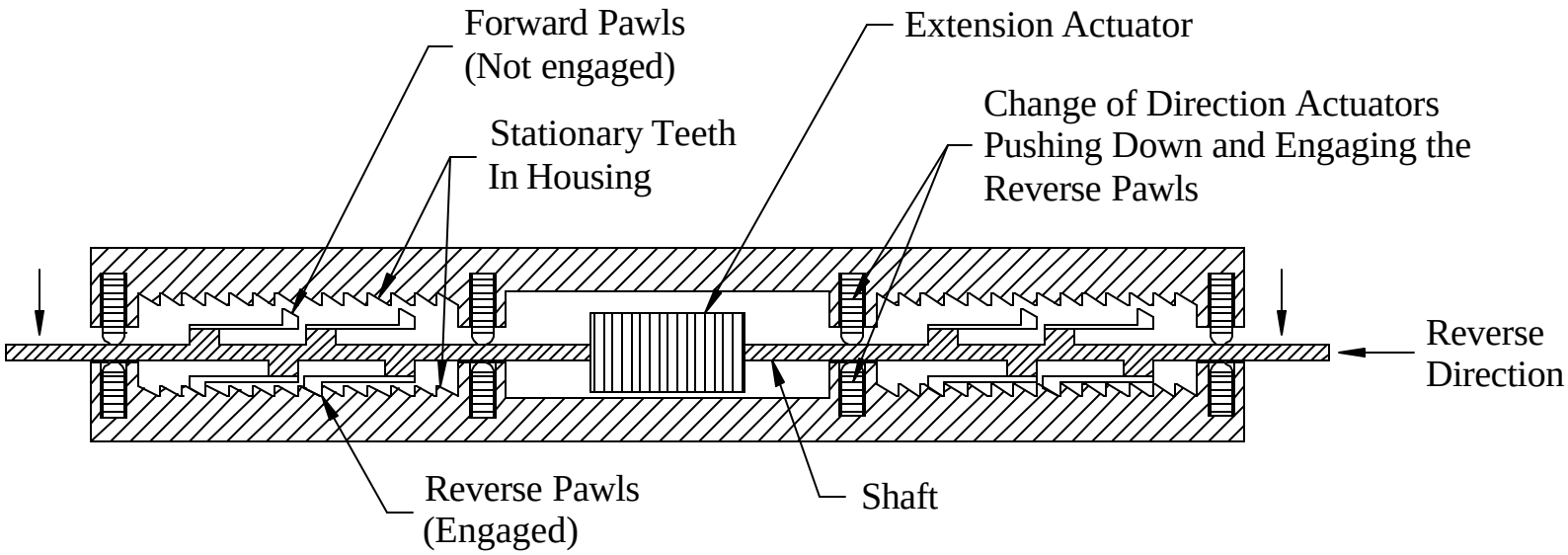
UCLA's MAD Actuator's push force is ultimately limited by the shear strength of interlocking micromachined teeth.



Steel MAD Prototype Performance:

- 500 N Force
- 3mm Travel
- 11 mm/s Speed

Inchworm-HMR Concept

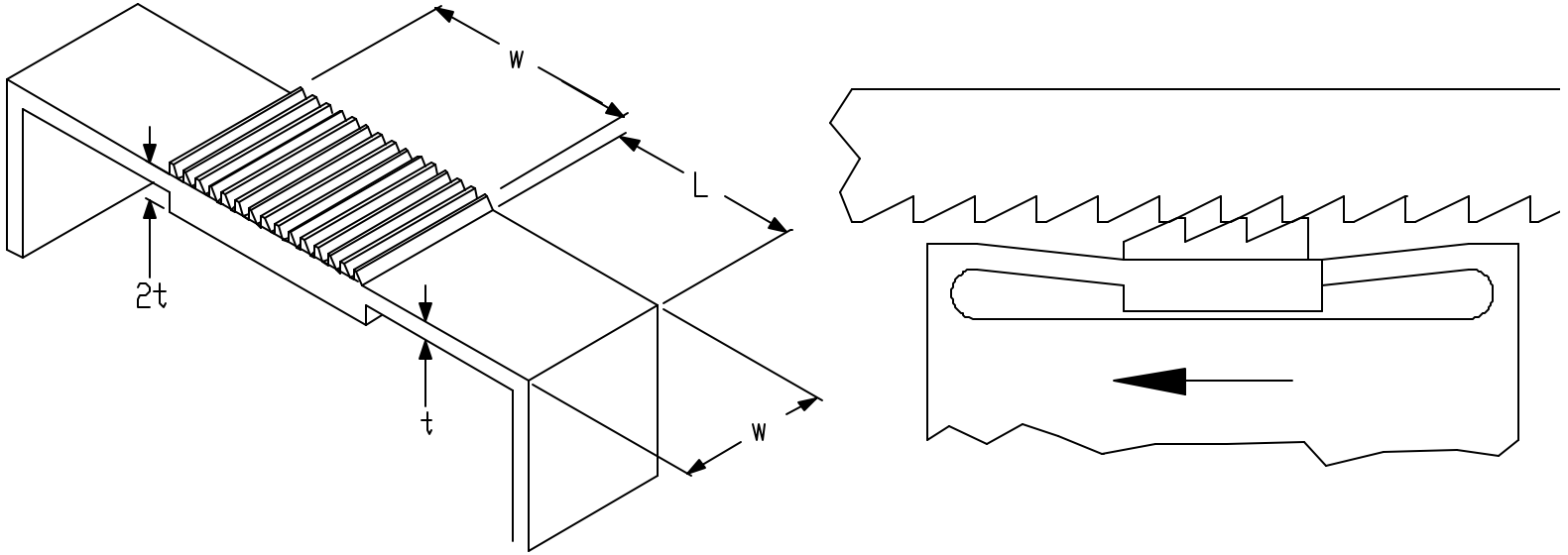


- Micromachined teeth and ratcheting pawls that passively slip and reset to mechanically rectify the oscillating motion of the PZT extension actuator.
- Direction changes are achieved by laterally shifting rotor to engage a separate set of teeth and pawls.

Why a Ratchet?

• MEMS-scale pawl teeth can passively reset in microseconds.

•Avoids the need for active control of teeth engagement and disengagement. (At the target motor cycle frequency of 5000 Hz, the teeth must reset in 10 microseconds without jamming or breaking and while operating under varying loads.)



Increasing Speed

Classic Inchworm speed is limited by:

- The response time and heat dissipation of the PZT actuators. (Both the extension and clamps.)

- Power output and efficiency of the drive and control electronics.

Inchworm-HMR Program will develop:

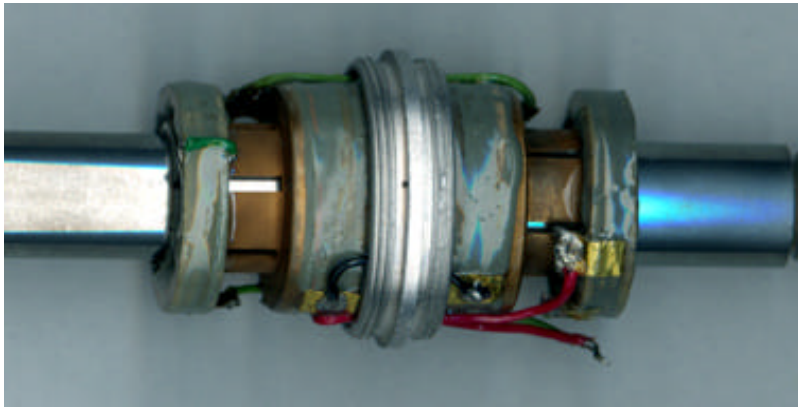
- Lower loss and high power density PZT actuators.

- High Efficiency Switching Regenerative Power Supplies and Amplifiers

Actuator Technology Comparison and Inchworm-HMR Performance Goals

Product	Technology	Speed (mm/Sec))	Force (N)	Mass (Kg)	Power Density (W/Kg)
Smoovy/RMB	DC motor and lead screw	1.65 *50% of Maximum*	6 *50% of Maximum*	0.0032	3
INCHWORM/ Burleigh (1 KHz Motor Frequency)	Piezoelectric stepping with smooth friction clamps.	1	10	0.010	1
MAD/UCLA (1KHz Motor Frequency)	Piezoelectric stepping MEMS-fabricated interlocking teeth.	11	500	0.1	55
INCHWORM-HMR Development (5 KHz Motor Frequency)	Piezoelectric stepping with MEMS-fabricated ratcheting teeth..	50	225	0.04	281

Summary



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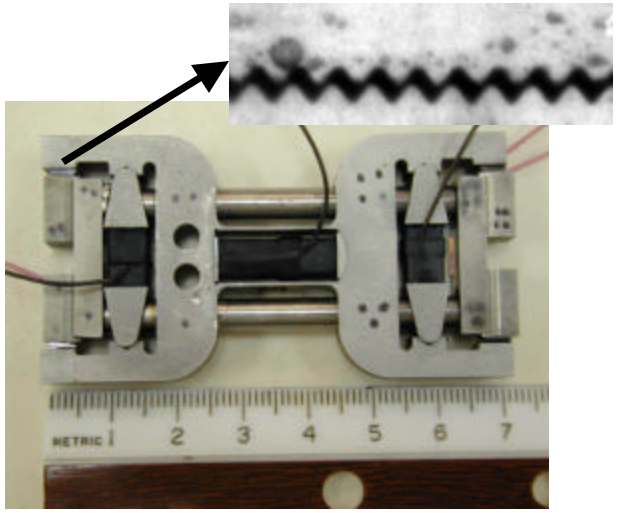

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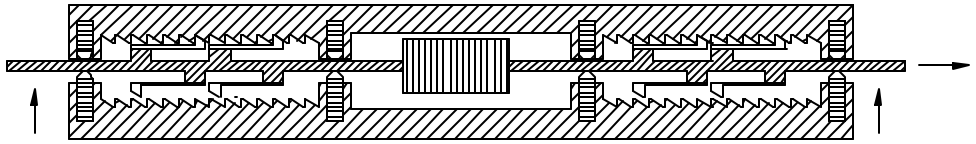

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